



Chapter Goals

- Understand hybrid fiber coax (HFC) networking concepts as a viable data medium.
- Identify and characterize dominant HFC limitations associated with Data Over Cable Service Interface Specifications (DOCSIS) data transmission.
- Understand the (DOCSIS) standard for data transport over Cable Television System (CATV).
- Become familiar with DOCSIS hardware deployment and resulting capabilities.
- Become aware of future applications of the DOCSIS standard to support advanced services.

Cable Access Technologies

Introduction

Historically, CATV has been a unidirectional medium designed to carry broadcast analog video channels to the maximum number of customers at the lowest possible cost. Since the introduction of CATV more than 50 years ago, little has changed beyond increasing the number of channels supported. The technology to provide high-margin, two-way services remained elusive to the operator.

During the 1990s, with the introduction of direct broadcast satellite (DBS) and digital subscriber line (DSL), the cable operators experienced a serious challenge to their existence by competing technologies threatening to erode market share of their single product.

DBS operators marketed more choice and better quality entertainment product through digital technology, whereas the incumbent local exchange carriers (LEC) proposed to offer a combination of voice, video, and data by means of DSL.

Fearing loss of market share and the need to offer advanced services to remain economically viable, key multiple system operators (MSOs) formed the Multimedia Cable Network System Partners, Ltd. (MCNS), with the purpose of defining a product and system standard capable of providing data and future services over CATV plants. MCNS proposed a packet-based (IP) solution in contention with a cell-based (ATM) solution promoted by IEEE 802.14. MCNS partners included Comcast Cable Communications, Cox Communications, Tele-Communications Inc., Time Warner Cable, MediaOne, Rogers CableSystems, and Cable Television Laboratories (CableLabs).

The Data Over Cable Service Interface Specification (DOCSIS) 1.0 standard that resulted from the MCNS effort was unanimously accepted as the North American standard, and vendors aggressively introduced products in compliance with this standard. MSOs defined upgrade and construction programs to increase the supporting bandwidth of their plants and to provide two-way functionality.

The DOCSIS 1.0 standard prescribes multivendor interoperability and promotes a retail model for the consumer's direct purchase of a cable modem (CM) of choice. To ensure multivendor interoperability, CableLabs subjects all products offered to rigorous testing. Equipment successfully passing all tests will be CableLabs Qualified for head-end Cable Modem Terminating System (CMTS), and CableLabs Certified for CM devices.

To date, the DOCSIS 1.0 standard is proving to be a universal success, with deployments now in operation worldwide.

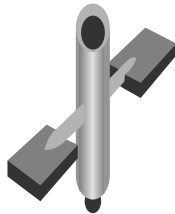
CableLabs, in conjunction with the vendor and user communities, is now in the process of defining DOCSIS 1.1 for the purpose of supporting Voice Over Internet Protocol (VoIP) and advanced security, and is also paving the way for advanced future multimedia services.

Evolution from One-Way Broadcast to Two-Way Hybrid Fiber Coax

A CATV network consists of a *head-end* location where all incoming signals are received and, regardless of their source, frequency-division multiplexing (FDM) is applied, amplified, and transmitted *downstream* for distribution to the complete cable plant.

Original CATV networks, as shown in Figure 22-1, were exclusively one-way, comprised of diverse amplifiers in cascade to compensate for the intrinsic signal loss of the coaxial cable in series with taps to couple video signal from the main trunks to subscriber homes via drop cables.

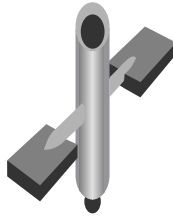
Figure 22-1 A Simple, One-Way Video Broadcast Topology Using Coaxial Cabling Exclusively



Besides being unidirectional, the long amplifier cascades resulted in a system with high noise that was inherently unreliable and failure-prone, in addition to being susceptible to lightning strikes and ingress noise from foreign radio frequency (RF) signals.

The first significant improvement to the CATV plant was the introduction of fiber-optic technology and the advent of the HFC plant (see Figure 22-2).

Figure 22-2 Simple HFC Distribution Network



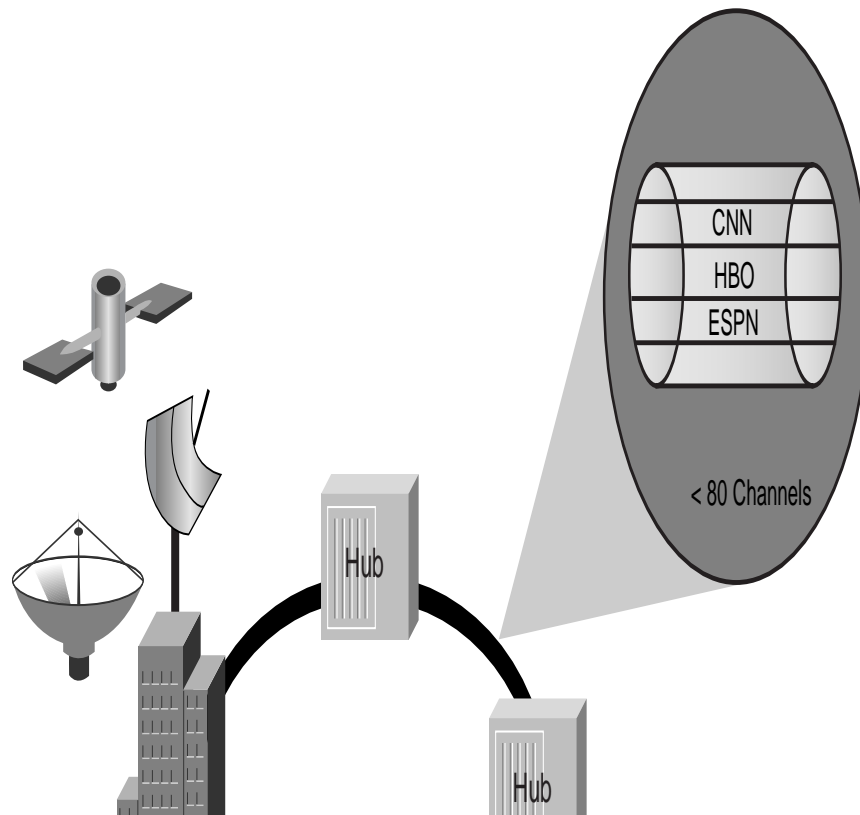
Portions of the coaxial cable and supporting amplification elements are replaced with multifiber optic cable from a head end or hub location. The aggregated video signal is used to modulate a downstream laser, which transmits the optical signal to an optical node, which in turn converts the signal from an optical to an electrical signal that can then be propagated downstream to the entire customer serving area.

It can be readily seen that the introduction of the fiber can significantly reduce the number of cascaded amplifiers consequently improving system reliability, the signal-to-noise ratio (SNR) of the downstream video signal, and potential system bandwidth. In addition, this makes the system ready for the next step to two-way operation. As an added benefit, HFC reduces operational and maintenance costs, and improves the immunity of the system to ingress noises.

Two-way operation is achieved by the addition of requisite upstream amplifiers in the amplifier housings, the addition of a narrow-band upstream laser in the optical node, a dedicated upstream fiber to the head end, and a compatible optical receiver to convert any upstream information to an electrical signal. When all components are in place, proper return path alignment is required.

By means of adding an optical RING topography, the cable network affords greater reliability, supports greater bandwidth with the capability to transport more information, and is ready to support two-way operation by the simple addition of requisite components, as illustrated in Figure 22-3.

Figure 22-3 Advanced HFC Network with Ring Topography



Network robustness, scalability, and flexibility is further improved by the introduction of the intermediate hub from which advanced services can ultimately be launched.

The HFC network and topography as outlined become the basic building blocks for developing access transport capabilities needed by the MSOs to compete in the dynamic communication environment.

Limitations and Specifications of the HFC Plant

The HFC network has the potential to offer tremendous bandwidth in the downstream or forward direction from the head end or hub to the customer. Depending upon the extent of the plant upgrade, the available bandwidth could be as much as from 54 to 860 MHz. Downstream channel bandwidths are determined by the individual country's video broadcast standards.

The historical broadcast video channel assignments limit the upstream or reverse direction from the customer to the spectrum between 5 to 42 MHz. This upstream spectrum is frequently hostile to return path connectivity due to the ingress of foreign interfering signals such as ham radio citizen band (CB), among other legitimate RF emissions.

Table 22-1 summarizes the specifications for the downstream direction, and Table 22-2 summarizes the specifications for the upstream direction.

A DOCSIS system must provide greater than 99 percent availability when forwarding 1500-byte packets at the rate of at least 100 packets per second. To achieve these criteria, certain CATV performance specifications are mandated on both the upstream and downstream spectrum.

Table 22-1 Downstream Cable Specifications

Downstream Parameter	Assumes nominal analog video carrier level (peak envelope power) in a 6-MHz channel with all conditions present concurrently and referenced to frequencies greater than 88 MHz
RF channel spacing (BW)	6 MHz
Transit delay, CMTS to most distant customer	Less than or equal to 0.800 ms
CNR in a 6-MHz band	Not less than 35 dB (analog video level)
C/I ratio for total power (discrete and broadband ingress signals)	Not less than 35 dB within the design BW
Composite triple-beat distortion for analog-modulated carriers	Not greater than -50 dBc within the design BW
Composite second-order distortion for analog-modulated carriers	Not greater than -50 dBc within the design BW
Cross-modulation level	Not greater than -40 dBc within the design BW
Amplitude ripple	0.5 dB within the design BW
Group delay ripple in the spectrum occupied by the CMTS	75 ns within the design BW
Microreflections bound for dominant echo	-10 dBc at less than or equal to 0.5 ms -15 dBc at less than or equal to 1.0 ms -20 dBc at less than or equal to 1.5 ms -30 dBc at less than or equal to 1.5 ms
Carrier hum modulation	Not greater than -26 dBc (5 percent)
Burst noise	Less than 25 ms at a 10 Hz average rate
Seasonal and diurnal signal level variation	8 dB
Signal level slope (50 to 750 MHz)	16 dB
Maximum analog video carrier level at the CM input, inclusive of above signal level variations	17 dBmV
Lowest analog video carrier level at the CM input, inclusive of above signal level variation	-5 dBmV

Good engineering, design, and maintenance practices for CATV plants ensure that these traditional video parameters can easily be met and maintained for operational systems. Parameters of primary concern, however, relate to signal level and noise.

Table 22-2 Upstream Cable Specifications

Upstream	Assumes all conditions present concurrently
Frequency range	5 to 42 MHz, edge to edge
Transit delay, most distant CM to nearest CM or CMTS	Less than or equal to 0.800 ms
Carrier-to-noise ratio	Not less than 25 dB
Carrier-to-ingress power (the sum of discrete and broadband ingress signals) ratio	Not less than 25 dB
Carrier-to-interference (the sum of noise, distortion, common path distortion, and cross-modulation) ratio	Not less than 25 dB
Carrier hum modulation	Not greater than -23 dBc (7 percent)
Burst noise	Not longer than 10 ms at a 1 kHz average rate for most cases
Amplitude ripple	0.5 dB/MHz (5 – 42 MHz)
Group delay ripple	200 ns/MHz (5 – 42 MHz)
Microreflections: single echo	-10 dBc at less than or equal to 0.5 ms -20 dBc at less than or equal to 1.0 ms -20 dBc at less than or equal to 1.0 ms
Seasonal and diurnal signal level variation	Not greater than 8 dB min to max

The greater challenge for the operator is to realize sufficient usable upstream bandwidth to achieve the systems throughput requirements for data or other services. The limited upstream bandwidth must often be shared with other services, ranging from impulse pay-per-view (IPPV), telemetry, and alarm gathering information from the active elements in the cable plant, as well as having to compete with interfering signals that radiate into the lower frequency range.

Because of the limited and often-hostile upstream bandwidth, the hardware design must implement diverse countermeasures to mitigate the effects of both fixed and transient harmful noise. In addition, the network designer must choose from the available remaining spectrum and often must implement bandwidth compromises for a DOCSIS deployment.

A combination of upstream signal quality measured by carrier-to-noise ratio (CNR), anticipated market penetration, services offered, and available upstream spectrum will ultimately dictate the physical configuration of the return-path physical layer.

DOCSIS Standards, Signaling Protocols, and Applications

The DOCSIS interface specifications enabled the development and deployment of data-over-cable systems on a nonproprietary, multivendor, interoperable basis for transparent bidirectional transfer of Internet Protocol (IP) traffic between the cable system head end and customer locations over an all-coaxial or hybrid-fiber/coax (HFC) cable network.

The system consists of a CMTS located at the head end, a coaxial or HFC medium, and a CM located at the premises of the customer, in conjunction with DOCSIS-defined layers that support interoperability and evolutionary feature capabilities to permit future value-added services.

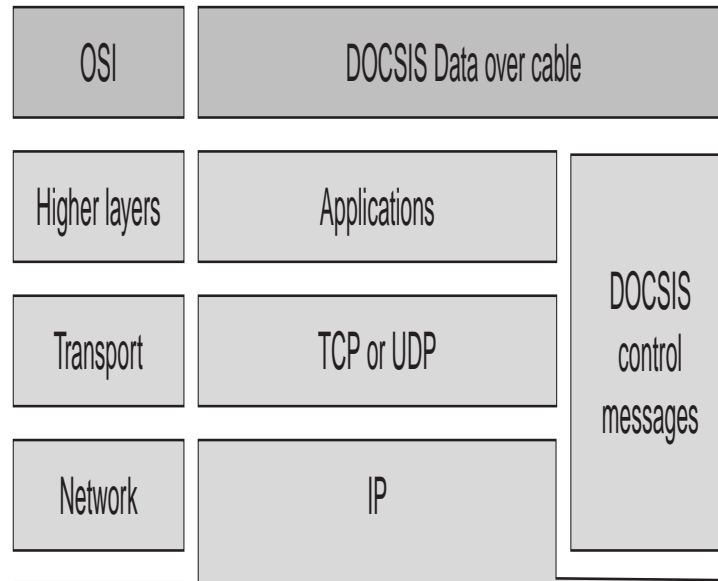
DOCSIS layer definitions are as follows:

- IP network layer
- Data link layer comprised of:
 - Logical Link Control (LLC) sublayer conforming to Ethernet standards
 - Link security sublayer for basic privacy, authorization, and authentication
 - Media Access Control (MAC) sublayer for operation supporting variable-length protocol data units (PDU) and featuring:
 - CMTS control of contention and reservation transmission opportunities
 - A stream of minislots in the upstream
 - Bandwidth efficiency through variable-length packets
 - Extensions for the future support of Asynchronous Transfer Mode (ATM) or other types of PDU
 - Support for multiple grade of service and wide range of data rates
- Physical (PHY) layer comprised of:
 - Downstream convergence layer conforming to MPEG-2 (Rec. H.222.0)
 - Physical Media Dependent (PMD) sublayer for:
 - Downstream based on ITU-T Rec J.83 Annex B with either 64 or 256 quadrature amplitude modulation (QAM), concatenation of Reed-Solomon and Trellis forward error correction (FEC), in addition to variable-depth interleaving
 - Upstream, employing:
 - Quadrature phase shift keying (QPSK) or 16 QAM
 - Support for multiple symbol rates
 - CM controlled and programmable from the CMTS
 - Frequency agility
 - Support for fixed-frame and variable-length PDU formats
 - Time-division multiple access (TDMA)
 - Programmable Reed-Solomon FEC and preambles
 - Capability to support future physical layer technologies

In addition, the specification defines means by which a CM can self-discover the appropriate upstream and downstream frequencies, bit rates, modulation format, error correction, and power levels. To maintain equitable service levels, individual CMs are not allowed to transmit except under defined and controlled conditions.

The DOCSIS layers are represented by Figure 22-4 and are compared with the classic OSI layer.

Figure 22-4 DOCSIS and OSI Protocol Layers



The DOCSIS physical layer permits considerable flexibility to ensure quality transmission can be achieved over cable plants of varying quality. Of significance are the optional upstream channel bandwidths and modulation choices available for both the upstream and downstream signal flows.

Based upon bandwidth and modulation options, in addition to DOCSIS-specified symbol rates, the total and effective data rates of DOCSIS facilities are summarized in Tables 22-3 through 22-5. The overhead generated by FEC inefficiency represents the difference between the respective rates.

Table 22-3 Nominal DOCSIS Downstream Data Rates in 6-MHz Channel

Modulation type	64 QAM	256 QAM
Symbol rate	5.057 MSs	5.360 MSs
Total data rate	30.34 Mbps	42.9 Mbps
Effective data rate	27 Mbps	38 Mbps

Table 22-4 Nominal DOCSIS Upstream Data Rates for QPSK

Bandwidth	200 kHz	400 kHz	800 kHz	1600 kHz	3200 kHz
Symbol rate	0.16 MSs	0.32 MSs	0.64 MSs	1.28 MSs	2.56 MSs
Total data rate	0.32 Mbps	0.64 Mbps	1.28 Mbps	2.56 Mbps	5.12 Mbps
Effective data rate	0.3 Mbps	0.6 Mbps	1.2 Mbps	2.3 Mbps	4.6 Mbps

Table 22-5 Nominal DOCSIS Upstream Data Rates for 16 QAM

Bandwidth	200 kHz	400 kHz	800 kHz	1600 kHz	3200 kHz
Symbol rate	0.16 MSs	0.32 MSs	0.64 MSs	1.28 MSs	2.56 MSs
Total data rate	0.64 Mbps	1.28 Mbps	2.56 Mbps	5.12 Mbps	10.24 Mbps
Effective Data Rate	0.6 Mbps	1.2 Mbps	2.3 Mbps	4.5 Mbps	9 Mbps

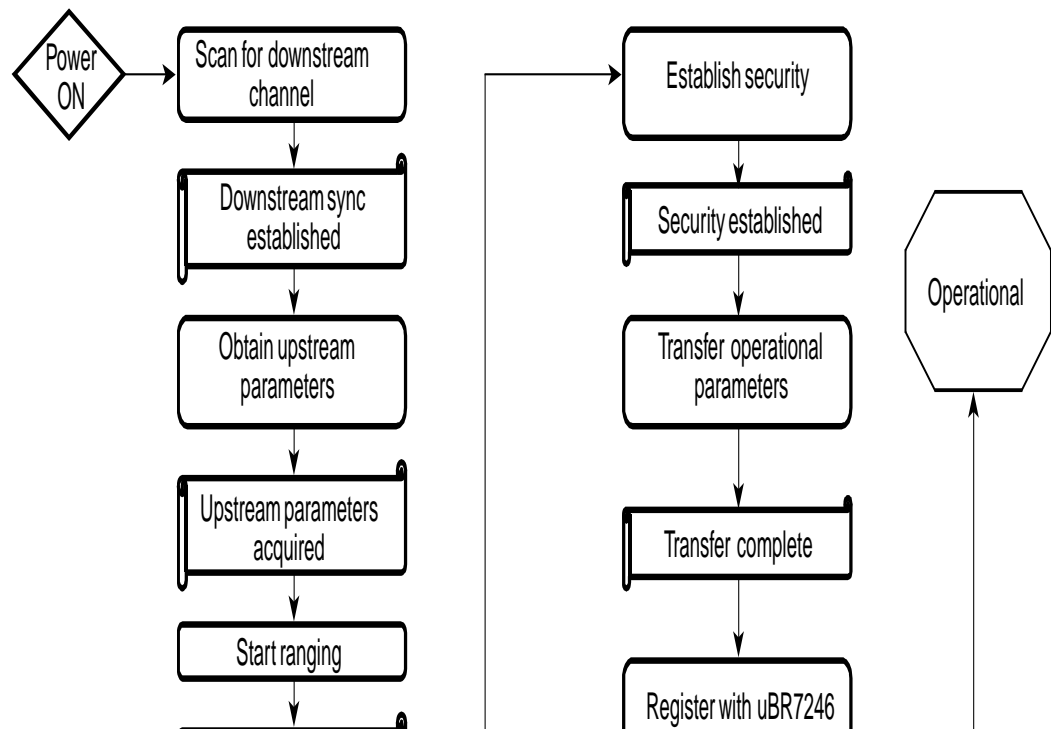
DOCSIS further specifies that for a system to become functional and operational, mandatory servers must interface the CMTS and CM deployments. These servers include the following:

- Dynamic Host Configuration Protocol (DHCP) server, as defined by RFC 2181. This server provides needed IP addresses for both the CM and subsequent PC devices that follow.
- Time of Day (TOD) server, as defined by RFC 868 for the purpose of time-stamping operational system events.
- Trivial File Transfer Protocol (TFTP) server, as defined by RFC 1350 for the purpose of registering and downloading CM configuration files for individual customer service. These configurations could include quality of service (QoS) parameters, baseline privacy (BPI) implementation, operating frequency assignments, the number of host devices, and so on.

For large-scale deployments, it is recommended that these servers be supported by dedicated hardware platforms to ensure rapid system response and scalability.

The DOCSIS specifications dictate a CM registration process as represented by Figure 22-5. In an environment equipped with a CMTS and supported with the required servers, a CM scans the downstream spectrum when it is initially powered on for a compatible RF channel carrying data adhering to DOCSIS physical layer characteristics. The CMTS periodically broadcasts upstream channel descriptors (UCD) over the DS channel, from which a CM will learn its assigned upstream operational frequency. The CM has now established both a US and a DS frequency.

Figure 22-5 Cable Modem Registration Sequence



The CMTS periodically transmits upstream bandwidth allocation maps (henceforth referred to as MAP) in shared time slots in the DS direction.

The CMTS assigns a temporary service identifier (SID) (typically $SID = 0$) to the CM, which begins a coarse power ranging (R1 using 3 dB increments) and time synchronization process between itself and the CMTS on a contention basis using shared time slots.

The CMTS periodically sends keepalive messages to verify link continuity between itself and all CM units in the same domain. When a CM receives its first keepalive message, it reverts to a fine power ranging (R2 using 0.25 dB increments).

Following the R2 process, a CM is considered to have established a *link* between itself and the CMTS, but the link will be broken if 16 consecutive keepalive messages are lost.

On a contention basis in shared time slots, using a temporary SID, a CM forwards a bandwidth request to the CMTS, which in turn forwards a grant to the CM, permitting it to forward upstream information in allocated time slots. The CM subsequently makes a DHCP discovery followed by a DHCP request. The CMTS forwards a DHCP acknowledgment from the DHCP server containing an IP address, a default gateway, the addresses of a TFTP and TOD server, and a TFTP configuration file name.

The CM subsequently initiates the TOD and TFTP process. From the TFTP server, the CM receives a configuration file containing QoS, security, applicable frequency assignments, and any new software images.

The CM forwards this configuration file to the CMTS and initiates a registration request. If the configuration file is valid, the CMTS assigns the CM a permanent SID and registers the CM to online status.

Following registration, the CM optionally initiates the activation of the 56-bit DES encryption algorithm to provide security between the CMTS and itself over the cable plant.

As CMs register, their individual status can be monitored remotely via access commands to the CMTS. Table 22-6 defines status messages from a Cisco universal broadband router.

Table 22-6 List and Definition of Show Cable Modem State Commands from a Cisco CMTS

Message	Message Definition
Offline	Modem is considered offline
init(r1)	Modem is sent initial ranging
init(r2)	Modem is ranging
init(rc)	Ranging is complete
init(d)	DHCP request was received
init(i)	DHCP reply was received; IP address was assigned
init(t)	TOD request was received
init(o)	TFTP request was received
online	Modem is registered and enabled for data
online(d)	Modem is registered, but network access for the CM is disabled
online(pk)	Modem is registered, BPI is enabled, and KEK was assigned
online(pt)	Modem is registered, BPI is enabled, and TEK was assigned
reject(m)	Modem did attempt to register; registration was refused due to bad MIC
reject(c)	Modem did attempt to register; registration was refused due to bad COS
reject(pk)	KEK modem key assignment was rejected
reject(pt)	TEK modem key assignment was rejected

DOCSIS prescribes that data forwarding through the CMTS may be transparent bridging or, as an alternate, may employ network layer routing or IP switching. It also specifies that data forwarding through the CM is link layer transparent bridging with modifications allowing the support of multiple network layers.

In addition, DOCSIS defines generic CMTS and CM hardware specifications to ensure multivendor interoperability in field deployments. These are summarized in Table 22-7.

Table 22-7 A Generic CMTS Hardware Specification

Parameter	Characteristic	
Frequency range	Upstream	5 to 42 MHz (5 to 65 MHz offshore)
	Downstream	88 to 860 MHz
Bandwidth	Upstream	200, 400, 800, 1600, 3200 kHz
	Downstream	6 MHz (8 MHz offshore)
Modulation modes	Upstream	QPSK or 16 QAM
	Downstream	64 or 256 QAM
Symbol rates	Upstream	160, 320, 640, 1280, 2560 Ksymbols/sec
	Downstream	5.056941 or 5.360537 Msymbols/sec
CMTS power level range		
upstream		
downstream		

For the DOCSIS availability criteria to be realized or exceeded, the hardware must support noise-mitigating countermeasures or properties to operate in the hostile upstream. For the upstream, the operator has a choice of either QPSK or 16 QAM enabling operation within a degraded CNR, but with reduced spectral efficiency.

Additionally, forward error correction (FEC) can be optionally configured to reduce the amount of data corrupted by noise. Furthermore, an optimal upstream BW can be selected by the operator to fit data channels between either noisy spectrum or spectrum assigned to other services.

The last countermeasure available is a concept of spectrum management, in which the selected upstream frequency, modulation, and channel bandwidth can be altered to ensure reliable access transmission between the CMTS and CM in case of transitory noise periods.

The physical characteristics of the generic DOCSIS 1.0 hardware, noise-mitigating countermeasures, and the associated cable plant parameters have been defined and specified in Table 22-8. Based on this information, and knowing the actual cable plants characteristics, the operator can now consider deploying hardware to develop a network.

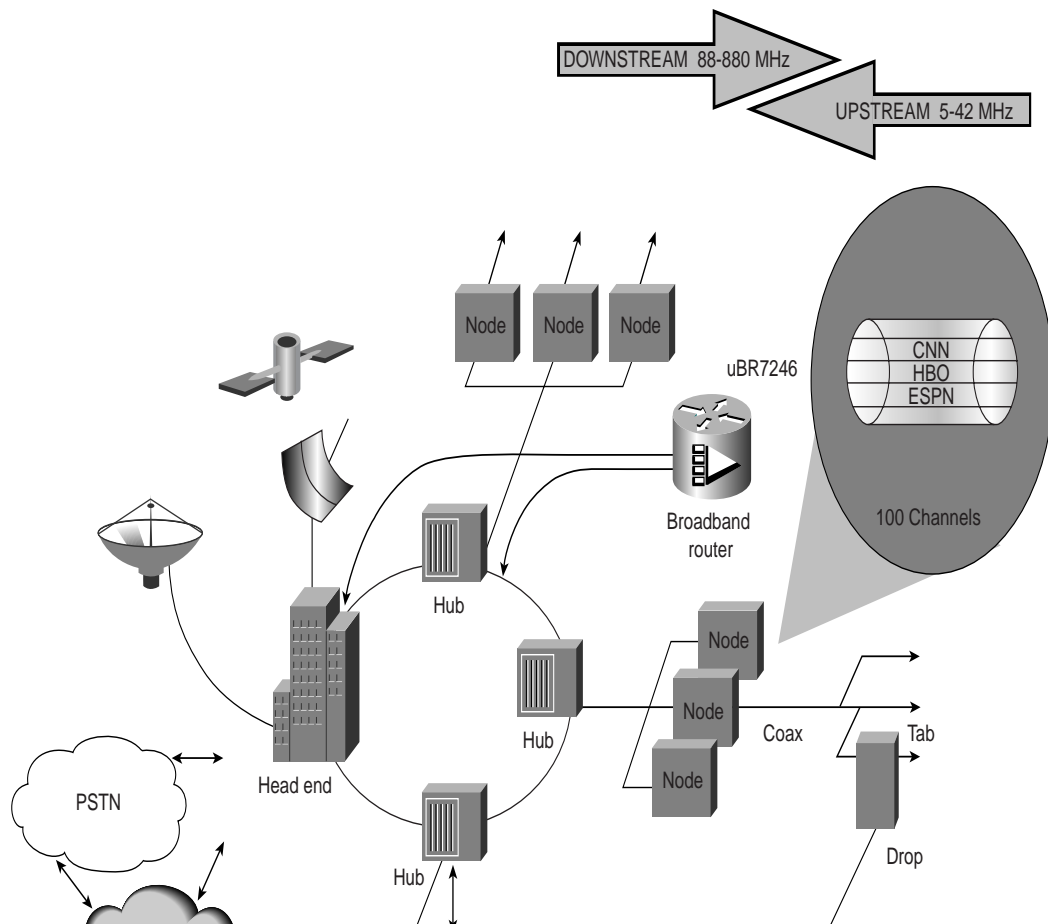
Table 22-8 Generic CM Hardware Specification

Parameter	Characteristic
CM power level range:	
Output	QPSK: 8 to 58 dBmV 16 QAM: 8 to 55 dBmV
Input	-15 to 15 dBmV
Transmission level	-6 to -10 dBc

DOCSIS Hardware Deployment and Resulting Service Capabilities

Assuming HFC CATV topography as shown in Figure 22-6, CMTS equipment could be deployed at both the hub and the head end locations. For the purpose of this application, the Cisco universal broadband router is considered. The uBR7246 is an integrated router with a capacity of up to four CMTS units, with CMTS units available with one downstream port and from one to six upstream ports. In addition, the universal broadband router can be equipped for backbone connectivity from a large selection of port adapters, ranging from T1/E1 serial to Packet Over SONET (POS), to Dynamic Packet Transport (DPT) and from 10BaseT Ethernet to High-Speed Serial Interface (HSSI).

Figure 22-6 CMTS Deployment Possibilities in a Typical HFC CATV Plant



When selecting the backbone connection option, an assessment of the total backbone traffic and the available medium must be considered. In all likelihood, for our example, the backbone from the hub location would be transported optically to the head end, where all traffic would be aggregated by either a router or an IP switch before being forwarded to the Internet or to the public switched telephone network (PSTN). Often, the MSO will provision a cache engine at the head end to reduce the bandwidth to the Internet and consequently reduce the facility lease cost.

Connectivity to the PSTN is often required to support either dialup Internet service, voice, or Telco return data service.

Telco return, if available from the MSO, is as an interim service offering because its plant topography has not been fully upgraded to two-way operation. In such applications, a high-speed downstream connection is established over the HFC plant, whereas the upstream connection is established via a Point-to-Point Protocol (PPP) connection over the telephone network, with a dialup modem at the customer premise and an access server located electrically before connecting to the Internet.

To emphasize the engineering considerations evaluated for establishing a DOCSIS network, a simple business case model will be evaluated. The relevant business parameters are summarized in Table 22-9. The analysis considers only residential and limited business customers supported by the head end location.

Table 22-9 Five-Year Business Plan Summary

Plant Growth	0.75 Percent per Annum	
High-speed data service offered:		
Residential	256 kbps DS	128 kbps US
Business	1.5 Mbps DS	512 kbps US
Penetration rates:		
Residential	3 percent in first year with 30 percent CAGR	
Business	Two in year two; add one per year thereafter	
Analysis assumptions:		
Residential activity factor	25 percent	
Business activity factor	25 percent	
Data peak factor	8 percent	

The business plan indicates that the DOCSIS service is for an existing serving area that will experience moderate growth, probably limited to new home construction, over the plan period. The operator intends to offer a single data product to each of the residential and business users within the serving area.

Penetration rate is the percentage of total homes passed in the serving area and represents the number of customers who buy the service.

The *activity factor* represents the percentage of subscribers who are actively online either uploading or downloading information.

The *peak factor* represents the relationship between the perceived or apparent bandwidth load of a system compared to the actual finite bandwidth available from the physical CMTS deployment. Peaking reflects the fact that data transfer to an individual user is typically during intervals of instantaneous duration.

The cable plant infrastructure (head end serving area) that is considered for this deployment has characteristics, assigned spectrum, and selected modulation as summarized in Table 22-10.

Table 22-10 Head End Serving Area Characteristics and Available Spectrum

HFC characteristics	Downstream: 88 to 750 MHz Upstream: 5 to 42 MHz
Head end serving area	25,000 homes passed 25 nodes (average of 1,000 homes each) CNR varying between 30 and 36 dB; average of 32 dB

Table 22-10 Head End Serving Area Characteristics and Available Spectrum

Available spectrum	Downstream: EIA channel 60 at 439.25 MHz Upstream: 32 MHz, 800 kHz bandwidth
Modulation	Downstream: 64 QAM Upstream: QPSK

The head end supports a local serving area of 25,000 homes passed, distributed among 25 optical nodes with upstream CNR ranging from 30 to 36 dB. The CNR is a significant parameter because it dictates the number of nodes that can be combined into a single receive port. DOCSIS requires a CNR of 25 dB, irrespective of the upstream modulation chosen for certified operation.

The selection of QPSK and bandwidth of 800 kHz will impact the return path data throughput rate.

From the business case variables, a five-year customer and traffic profile summary is prepared and summarized as in Table 22-11.

The table indicates that the number of homes passed and the penetration rates have increased considerably over the evaluation, with the resultant perceived bandwidth to be processed by the CMTS equipment at the head end.

The number of CMTS units to support the perceived load must be determined considering the use of the Cisco uBR-MC16C consisting of one downstream and six upstream ports. First, however, a valid upstream aggregation scenario must be established.

Consider combining three nodes, each having a CNR of 36 dB, resulting in an aggregated CNR of approximately 27 dB that comfortably exceeds the DOCSIS criteria.

We must now determine the quantity of CMTS units to satisfy this application:

$25 \text{ nodes} / 3 \text{ nodes per receiver} = 9 \text{ receivers}$, indicating a need for two uBR-MC16C units

Considering the 800 kHz QPSK upstream limitations, the hardware selection must be validated against the traffic analysis for the business plan, as summarized in Table 22-11.

Table 22-11 Head End Customer and Traffic Profile

	Year 1	Year 2	Year 3	Year 4	Year 5
Homes passed	25,000	25,188	25,376	25,666	25,758
Residential customer	750	982	1286	1685	2207
Business customer		2	3	4	5
	DS 48M	DS 64M	DS 84M	DS 100M	DS 144M
Total traffic	US 24M	US 32M	US 42M	US 55M	US 72M

- Downstream Validation

Two uBR-MC16C resulting in $2 \times 27 = 54$ Mbps, compared to Year 5 requirement of $144/8 = 18.1$ Mbps (where 144 MBps is the Year 5 apparent BW and 8 is the data peaking factor)

- Upstream Validation

Two uBR-MC16C with 9 active receivers configured for QPSK and 800 kHz BW, resulting in $9 \times 1.2 = 10.8$ Mbps, compared to Year 5 requirement of $72/8 = 9$ Mbps (where 72 MBps is the Year 5 apparent BW and 8 is the data peaking factor)

- Subscriber Limit Validation

The total number of Year 5 subscribers is $2207 + 5 = 2212$ which is well within the suggested limit of 1200 subscribers per CMTS.

Based on the analysis of this simple business case, the initial deployment of CMTS hardware will meet the needs of the entire five-year plan and beyond, without compelling the operator to upgrade the configuration.

Future DOCSIS Applications

This chapter describes the DOCSIS 1.0 product definition intended to support high-speed data over a cable network. The standard is evolving to DOCSIS 1.1 to support additional services and future applications, which coincide with product enhancements to support the needs of the market to ensure network reliability, and high system availability.

Planned future services and applications include telephony based upon Voice over Internet Protocol (VoIP), video over IP using Motion Picture Expert Group (MPEG) frame format, quality of service (QoS), and enhanced security definitions. At the same time, CM and set top box (STB) devices capable of supporting these and other services are being introduced.

When considering the simultaneous support of these new services and applications, a more extensive planning concept must be considered.

Summary

Historical coaxial broadcast networking was described in this chapter, and its inherent detriments to advanced services were identified. HFC networking was included, with a brief description of its advantages and benefits capable of supporting high-speed data connectivity.

The limitations of prevailing HFC designs, DOCSIS availability criteria, and requisite cable plant specifications and terminology were addressed as well.

In addition, this chapter summarized the DOCSIS standard, signaling protocol, requisite supporting servers, generic product specifications, and applications. Representative CM status messages as viewed at the CMTS were provided to reflect parameters and tools critical for the operational aspects of a DOCSIS system.

Finally, future services and applications were identified to coincide with the evolution to DOCSIS 1.1.

Review Questions

Q—Describe the advantages or benefits offered by an HFC network.

A—HFC networks provide increased bandwidth, increased reliability, ready support for two-way operation, improved noise immunity, and reduced operation and maintenance costs.

Q—Identify the process of providing two-way operation of an HFC cable plant.

A—Two-way operation can be established on an HFC cable plant by installing the narrow-band upstream amplifiers in the amplifier housings, adding a narrow-band return laser at the optical node, providing an optical return path, and placing an optical receiver at the head end or hub location. Proper alignment procedure of the return path is also required.

Q—Describe the upstream and downstream bandwidths associated with the DOCSIS standard.

A—The DOCSIS bandwidth limitations are 5 to 42 MHz for the upstream direction, and 54 to 860 MHz for the downstream direction.

Q—*Summarize the DOCSIS availability criteria.*

A—A DOCSIS system must provide greater than 99 percent availability when forwarding 1500-byte packets at a rate of 100 packets per second when the cable plant meets the published DOCSIS system specifications.

Q—*Identify the DOCSIS-defined networking layers.*

A—The DOCSIS-defined layers consist of the IP network Layer, the data link layer, and the physical (PHY) layer.

Q—*Identify the DOCSIS 1.0 servers, and describe their respective purposes in the network.*

A—DOCSIS servers include the DHCP server (RFC 2181), which provides IP addresses to both the CM and PC devices; the TFTP server (RFC 1350), which registers and downloads CM configuration files; and the TOD server (RFC 868), which provides a time stamp to operational system events.

Q—*What are the facilities in which an MSO might deploy the universal broadband router?*

A—The universal broadband router can be deployed as needed in both the head end and hub locations.

Q—*Define Telco return and tell when this application might be considered.*

A—Telco return describes a data service that provides high-speed downstream connectivity over the coax plant, and low-speed connectivity over the PSTN. This application is typically used in rural networks, where the upgrade cost is prohibitive, or as an interim networking solution permitting the MSO to offer service while the cable plant is being upgraded for two-way service.

Q—*List a few of the properties and future applications associated with DOCSIS 1.1.*

A—DOCSIS 1.1 will support VoIP, enhanced security, packet concatenation and fragmentation, as well as QoS. Service applications include telephony and video.

For More Information

Books

- Azzam, Albert, and Niel Ransom. *Broadband Access Technology*. New York: McGraw-Hill, 1999.
- Ciciora, Walter, James Farmer, and David Large. *Modern Cable Television Technology*. Boston: Morgan Kaufmann Publishers Inc., 1998.
- Grant, William. *Cable Television*, Third Edition. New York: GWG Associates, 1997.
- Raskin, Donald, and Dean Stoneback. *Broadband Return Systems for Hybrid Fiber/Coax Cable TV Networks*. New York: Prentice Hall PTR, 1997.
- Thomas, Jeff. *Cable Television: Proof of Performance*. New York: Prentice Hall PTR, 1995.

URLs

- <http://www.cablelabs.com>
- <http://www.cablemodem.com>
- <http://www.cabletelephony.com>

<http://www.catv.org/modem.com>

<http://www.hukk.com>

Magazines

Cablevision. 8773 South Ridgeline Blvd., Highland Ranch, Co 80126. <http://www.cablevisionmag.com>.

Cableworld. Intertec Publishing, a Primedia Company, 9800 Metcalf Ave., Overland Park, KS 66212-2215. <http://cableworld.com>.

CED (Communications Engineering & Design). P.O. Box 266007, Highland Ranch, CO 80163-6007. <http://www.cedmagazine.com>.